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ARTICLE

Combined Effect of Aging and Irradiation on Physicochemical Quality of Pork Shoulder

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Abstract The effect of combined electron-beam irradiation and aging temperature of pork on microbiological and physicochemical properties was investigated. The samples from pork shoulder were irradiated with 0 or 2 kGy, vacuum-packaged, and assigned randomly to an aging temperature (2°C, 10°C, or 25°C) during 8 d. On 4 d of aging at 25°C, total aerobic bacteria of non-irradiated ones reached 7 Log CFU/g which is no salable levels. Shear force values of irradiated meat after aging for 2 and 4 d at 25°C was lower than those aged at 2°C. Irradiated samples at 2°C had lower cooking loss after 2 and 8 d of aging, compared with other aging temperatures. Irradiation did not accelerate 2-thiobarbituric acid reactive substance (TBARS) value when aged up to 4 d. Irradiated samples aged at 10°C and 25°C for 8 d scored significantly higher TBARS values. With an increased aging period, a* and b* in irradiated samples at 2°C slightly increased, but irradiation caused negligible changes in meat color. The highest contents of a desirable nucleotide flavor compounds (inosine-5-phosphate) were observed in pork at 2°C when aged for 4 and 8 d, while the lowest contents were observed at 25°C. Aging in irradiated pork for 8 d at 2°C resulted in optimal condition with improved meat quality and minimal microbiologically negative defect.

Keywords electron beam irradiation, aging temperature, pork, meat quality, nucleotide flavor compounds

Introduction

Irradiation of meat has been considered to be the most efficient technology for inhibiting proliferation of pathogenic microbes without fascinating nutritional traits (WHO, 1999). The WHO, FAO, the International Atomic Energy Agency (IAEA), and the US FDA who are very proficient has given the approval for using the irradiation on wholesomeness of irradiated food (Sohn et al., 2009).

Meat irradiation at low-dose is used to minimize meat quality changes (Zhu et al.,

2004). Along with the irradiation sources, electron beam (EB) processing dose not generate any radioactive wastes, process time is relatively short with minimal temperature expansion, and consumers favors (Black and Jaczynski, 2006). However, it can influence lipid oxidation, color changes, and off-odor of meat, which may generate negative consumer responses (Jo and Ahn, 2000a). Pork shoulder is popular and demanding cuts in Asian markets and the price are much higher compared with other retail cuts (KMTA, 2017). Moreover, irradiation of meat cuts in relation to various quality aspects were studied in terms of nutritional and sensory qualities (Fu et al., 1995; Giroux et al., 2001). However, very few research has been performed on the quality and storability of pork shoulder by EB-irradiation.

Even so, aging improves the tenderness and texture of meat, but also associated with greater loss during cooking (Huff-Lonergan E, 2005; Straadt et al., 2007). Pork has not gained the same popularity of aging techniques due to its relatively tender texture compared to beef. However, aging of pork shoulder can help it to be more tender and juicy. Several factors like temperature and time can be factors affecting aging in meat (Lee et al., 1996). Aging methods, periods, or temperatures during aging have yet to be explored due to production costs, operational efficiencies, and variation in the physicochemical properties of pork (Frenzel et al., 2014). A number of research has been conducted entitled of beef aging and well concerned about the quality and sensory traits of aged meat (DeGeer et al., 2009). To shorten aging time, higher temperature aging technique was applied to beef (Yim et al., 2016). Based on the results of microbiological safety, high temperature aging method was problematic in safety issues (Yim et al., 2016).

Although numerous studies have been conducted to find out the effect of irradiation on meat quality, very limited data is available on combined effect of aging and irradiation on the pork quality. Therefore, the objective of this study was not only to establish optimal conditions for aging by examining the impacts of aging at different temperatures and times of pork shoulder, but also to establish a pork resulted in a safe and quality product guide with proper physicochemical quality using EB irradiation.

Materials and Methods

Sample preparation and irradiation

Pork shoulder (mainly M. *supraspinatus*) was selected from 6 different pig carcasses for replication sample design from a carcass processing center (Daejeon, Korea) within 2 days from the time of slaughtering. After visible fats trimmed out, meat samples were sliced into a thick piece of 1 cm, which is enough to be irradiated over the whole sample. After vacuum packaged, there were stored at 5℃ overnight and irradiated next day.

Using a Linear Accelerator each prepared sample was irradiated at 2 kGy which is checked by an alanine dosimeter and then meat samples (irradiated and non-irradiated) were returned to a 4℃ room without any delay and aged for 8 d. The microbiological, shear force, cooking loss, lipid oxidation, color and nucleotides analyses were performed at different aging temperatures (2℃, 10℃, or 25℃) on 0, 2, 4, and 8 d.

Microbial and physicochemical analysis

Ten grams of sample were aseptically homogenized after adding 90 mL of sterile solution in a sterile Stomacher bag for 2 min (BagMixer® 400, Interscience, France). Consequently the diluents were planted onto aerobic plated count agar (Difco Laboratories), incubated at 37℃ for 45 h. The total number of colonies observed on plate of each sample after incubation was counted and expressed as log of colony forming units per gram (Log CFU/g).

Shear force (kg·f) was measured by the method (Yim et al., 2016). After cooking samples sliced with 2 cm-thickness in an electric grill (EMG-533, AIJIA, Hong Kong, China) up to 70°C, cooking loss was determined as follows: cooking loss (%)=100×(raw meat weight – final cooked meat weight)/raw meat weight. Lipid oxidation was determined as 2-thiobarbituric acid reactive substance (TBARS) values, following the slightly modified method (Ahn et al., 1998). Color parameters of sample surfaces were evaluated using a portable colorimeter (CR-200, Konica Minolta, Japan) from three randomly different locations. Flavor-related nucleotides in meats were measured according to the modified method described by (Yim et al., 2016). The peaks for individual nucleotides of the samples were branded with the retention time for the subsequent standards: inosine-5-phosphate (inosine monophosphate, IMP), inosine, hypoxanthine (Sigma, Agilent, USA); using the area of each peak, the concentration of nucleotides were calculated.

Statistical analysis

The experiment was performed with 3 independent trials having 3 observations for each treatment combination following in each trial. Data from each trial of experiment were analyzed using SAS software (SAS, 2003). Two-way analysis of variance (ANOVA) was performed. The differences among the mean values were determined by the Duncan's multiple comparison test at $p<0.05$, when the significant differences were detected. The mean values with standard error of the means (SEM) were reported.

Results and Discussion

Aging temperature, periods, and irradiation treatment influenced TAB of pork shoulder (Table 1). As aging temperature and

Table 1. Effect of different aging temperature on total aerobic bacterial counts (Log CFU/g) in pork shoulder treated by electron beam irradiation

Storage (day)	Temperature (°C)	Irradiation dose (kGy)		
		0	2	SEM[1)]
0	-	3.22^{x}	2.71^{y}	0.06
2	2	3.60^{c}	3.58^{b}	0.08
	10	3.99^{b}	3.90^{a}	0.04
	25	6.18^{ax}	3.90^{ay}	0.09
	SEM[2)]	0.08	0.07	
4	2	4.22^{c}	4.17^{c}	0.05
	10	5.07^{bx}	4.45^{by}	0.04
	25	7.12^{ax}	4.58^{ay}	0.02
	SEM	0.04	0.04	
8	2	4.42^{cx}	4.31^{by}	0.02
	10	5.12^{bx}	4.51^{ay}	0.05
	25	7.28^{ax}	4.60^{ay}	0.03
	SEM	0.02	0.05	

[1)] n=9, [2)] n=24 .
[a–c] Values with different letters within the same column differ significantly ($p<0.05$).
[x,y] Values with different letters within the same row differ significantly ($p<0.05$).

periods increased, TAB increased. This agrees with (Borch et al., 1996), who observed as refrigeration temperatures decreased, TAB decreased. However, TAB of irradiated pork shoulder samples was lower compared with the non-irradiated ones under the same aging tempeature. TAB of irradiated shoulders showed irradiation effectively controlled the growth of microorganisms during aging at 25℃. TAB of non-irradiated ones at 25℃ was in the range 6 Log CFU/g at 2 d and these microorganisms reached a level of 7 Log CFU/g after 4 d of storage which is no salable levels. The results showed TAB multiplied hastily in case of non-irradiated and aged samples at 25℃ after 2 d. Our investigation suggested that irradiation improved the microbiological safety of pork at 10℃ and 25℃ by reducing the TAB after 4 d of storage. However, TAB increased slightly in aged samples up to 8 d at 2℃. This result was agreed with the study reported by (Frenzel et al., 2014).

The consequence of different aging temperature on shear force values in non- and irradiated pork shoulders during the aging time is reported in Table 2. It was found that regardless of irradiation, the shear force values decreased as the aging time and temperature increased. In particular, shear force values of irradiated meat after aging for 2 and 4 d at 2℃ was higher than those aged at 25℃ ($p<0.05$). The decrease in shear force values in aging could be due to the degradation of myofibrillar components (Ba et al., 2014). Frenzel et al. (2014) suggested that aging temperatures did not affect the shear force values, but shear force values decreased as the aging periods increased. Recently, (Kim et al., 2018) reported however, the dilapidation of sarcoplasmic and myofibrillar proteins were greater in beef with aging temperatures of 14℃ than that of 4℃. In addition, EB and X-ray irradiated beef showed slower autolysis of calpain-1 but this did not affect tenderness. Results from our study also showed that, as pork aged, the shear force values decreased.

As shown in Table 3, with an increased aging time and temperature, cooking loss increased. In particular, the cooking loss of irradiated meat after aging for 2 and 8 d at 2℃ was lower than those aged at 10℃ and 25℃ ($p<0.05$). The cooking loss showed no differences among the irradiated and non-irradiated samples after aging for 4 d. (Frenzel et al., 2014) noted that

Table 2. Effect of different aging temperature on shear force values of pork shoulder treated by electron beam irradiation

Storage (day)	Temperature (℃)	Shear force values (kg·f)		
		Control	Irradiated (2 kGy)	SEM[1)]
0		2.17^{y}	3.27^{x}	0.18
2	2	1.83^{ay}	2.25^{ax}	0.07
	10	1.83^{a}	1.93^{b}	0.08
	25	1.58^{by}	1.91^{bx}	0.06
	SEM[2)]	0.06	0.08	
4	2	1.57^{y}	1.90^{ax}	0.08
	10	1.48	1.63^{ab}	0.12
	25	1.47	1.44^{b}	0.07
	SEM[2)]	0.08	0.09	
8	2	1.40	1.43	0.08
	10	1.39	1.37	0.06
	25	1.37	1.36	0.13
	SEM	0.10	0.09	

[1)] n=12, [2)] n=24 .
[a–c] Values with different letters within the same column differ significantly ($p<0.05$).
[x,y] Values with different letters within the same row differ significantly ($p<0.05$).

Table 3. Effect of different aging temperature on cooking loss of pork shoulder treated by electron beam irradiation

Storage (day)	Temperature (℃)	Cooking loss (%)		
		Control	Irradiated (2 kGy)	SEM[1)]
0		10.21	10.46	0.27
2	2	9.62	10.40[b]	0.67
	10	13.02	13.24[a]	1.05
	25	13.15	14.32[a]	0.95
	SEM[2)]	1.03	0.77	
4	2	15.07	14.52	0.94
	10	15.83	15.22	1.21
	25	18.00	16.85	0.87
	SEM[2)]	0.87	1.12	
8	2	18.77	19.80[b]	0.92
	10	20.48[y]	24.86[ax]	1.16
	25	21.88[y]	27.39[ax]	0.77
	SEM	0.96	0.97	

[1)] n=12, [2)] n=24 .
[a–c] Values with different letters within the same column differ significantly ($p<0.05$).
[x,y] Values with different letters within the same row differ significantly ($p<0.05$).

cooking loss was not significantly affected by aging periods and temperature and the explanation of the variances between cooking loss and aging was not clearly obvious. Shin et al. (2014) demonstrated that the different doses of X-ray did not impinge on the cooking loss of irradiated pork sausage because the meat of proteins were segregated by X-ray. However, rradiated samples after aging for 8 d were higher than non-irradiated ones at 10℃ and 25℃ ($p<0.05$).

Lipid oxidation, as determined by TBARS values, is presented in Table 4. As the time and temperature of aging went up, TBARS scores slightly increased regardless of irradiation conditions. The initial TBARS values did not change at irradiated samples until day 4, but drastically increased at 8 d. This is due to the fact that samples were packaged under vacuum conditions. Vacuum-packaging is normally better than aerobic for storage of irradiated meat because vacuum-packaging minimizes lipid oxidation in meat (Du et al., 2001). The storage temperature was a major factor of the rate of lipid oxidation as TBARS values were the lowest for samples at 2℃ after aging for 8 d while the values were highest at 25℃ ($p<0.05$). Generally, irradiation forwarded lipid oxidation of meat during storage only under the aerobic conditions (Ahn et al., 1998; Ahn and Nam, 2004; Davis et al., 2004; Jo and Ahn, 2000b). Irradiation did not increase lipid oxidation up to 4 d. This findings are accordant with the previous study (Li et al., 2017) reporting irradiation would not induce immediate TBARS surge at the beginning of pork aging of 3 d. Irradiation cannot increase lipid oxidation in dry-cured shoulder hams and low-dose irradiation is efficient for falling lipid oxidation (Jin et al., 2012). Mattison et al. (1986) also reported low dose irradiation on pork loin had no effect on TBARS values. The irradiated samples showed only a little higher TBARS values than the non-irradiated control at 10℃ and 25℃ after aging for 8 d ($p<0.05$). From our study, lipid oxidation might be compacted at low aging temperature (2℃) and these results were consistent with a prior study (Lee et al., 1996). Thus, our results showed that aging pork shoulders up to 8 d at 2℃ resulted in relatively safe in terms of lipid oxidation.

Color changes in aging periods, temperature and irradiation were not consistent (Table 5). Thus, it indicates that low-dose

Table 4. Effect of different aging temperature on thiobarbituric acid reactive substance (TBARS, mg malonedialdehyde/kg meat) values of pork shoulder treated by electron beam irradiation

Storage (days)	Temperature (℃)	TBARS (mg malonedialdehyde/kg meat)		
		Control	Irradiated (2 kGy)	SEM[1)]
0		0.22	0.24	0.01
2	2	0.28^{c}	0.30^{b}	0.01
	10	0.32^{b}	0.31^{b}	0.00
	25	0.36^{a}	0.38^{a}	0.02
	SEM[2)]	0.01	0.01	
4	2	0.31^{b}	0.31^{b}	0.01
	10	0.31^{b}	0.33^{b}	0.01
	25	0.37^{a}	0.38^{a}	0.01
	SEM[2)]	0.01	0.01	
8	2	0.31^{c}	0.33^{c}	0.01
	10	0.36^{by}	0.40^{bx}	0.01
	25	0.41^{ay}	0.44^{ax}	0.01
	SEM	0.01	0.01	

[1)] n=12, [2)] n=24 .
$^{a–c}$ Values with different letters within the same column differ significantly ($p<0.05$).
^{x,y} Values with different letters within the same row differ significantly ($p<0.05$).
TBARS, thiobarbituric acid reactive substance.

Table 5. Effect of different aging temperature on Hunter color values of pork shoulder treated by electron beam irradiation

Storage (days)	Temperature (℃)	L*			a*			b*		
		Control	Irradiated (2 kGy)	SEM	Control	Irradiated (2 kGy)	SEM	Control	Irradiated (2 kGy)	SEM[1)]
0		50.98	50.25	0.69	18.64	19.22	0.26	5.01	5.34	0.18
2	2	55.73^{ax}	47.63^{y}	0.63	17.54^{by}	18.98^{x}	0.19	5.18^{b}	5.01	0.20
	10	50.53^{bx}	46.10^{y}	0.75	18.94^{a}	19.00	0.27	6.32^{ax}	4.91^{y}	0.34
	25	49.68^{b}	47.57	0.90	19.19^{a}	18.79	0.24	5.11^{b}	4.94	0.30
	SEM[2)]	0.64	0.87		0.22	0.25		0.16	0.37	
4	2	48.62^{by}	52.71^{ax}	1.04	19.18^{a}	19.44	0.31	6.16^{b}	6.52^{b}	0.57
	10	48.70^{b}	49.36^{b}	0.95	19.84^{ax}	18.80^{y}	0.18	5.68^{by}	7.14^{abx}	0.34
	25	56.59^{a}	52.82^{a}	1.62	17.39^{by}	18.89^{x}	0.29	8.36^{a}	8.09^{a}	0.35
	SEM	1.46	0.97		0.29	0.24		0.52	0.33	
8	2	45.66^{b}	48.86	1.07	19.87^{a}	19.78^{a}	0.41	5.76^{y}	6.60^{x}	0.21
	10	50.72^{ax}	46.56^{y}	0.90	18.80^{ab}	19.17^{a}	0.34	6.57	5.62	0.34
	25	52.21^{a}	48.63	1.44	17.57^{b}	17.25^{b}	0.65	6.65	5.97	0.49
	SEM	1.17	1.14		0.56	0.38		0.26	0.44	

[1)] n=9, [2)] n=24 .
$^{a–c}$ Values with different letters within the same column differ significantly ($p<0.05$).
^{x,y} Values with different letters within the same row differ significantly ($p<0.05$).

irradiation did not influence the meat color and cause discoloration problem of pork shoulder from all stages of aging, affirming the previous results (Nam and Ahn, 2003; Shin et al., 2014). L* in control at 2℃ gradually decreased whereas a* in both groups and b* in irradiated groups slightly increased as aging time increased. This result agrees with (Li et al., 2017) who reported that a* and b* of pork increased between day 1 and 8 with aging period. Especially, a* were highest for samples at 2℃ after aging for 8 d, regardless of irradiation. This coincides with the finding of (Kim et al., 2012) who reported that storage at 4℃ tended to decline the L* of non-irradiated sausages, while a* and b* tended to increase. The changes of a* in the irradiated sausages during aging could be linked to the demolition of NO-myoglobin by irradiation progression (Kim et al., 2012).

Flavor-linked nucleotide compounds are generated from the decay of adenosine-5-triphosphate (ATP) (Flores et al., 1999). Before slaughter, ATP is the foremost compound in muscle, while huge amounts of IMP and little amounts of ATP, adenosine-5-monophosphate (AMP), and adenosine-5-diphosphate ADP were found in muscles after slaughtered (Lee and Lee, 2001). ATP converted into AMP by dephosphorylation and is then become to IMP, which contributes to the good taste and imparts flavor to the meat. IMP changes to inosine, which has a acerbic feel and then to hypoxanthine, which has a bitter taste (Tikk et al., 2006). The nucleotides of pork were influenced by irradiation, aging periods, and temperature (Table 6). From these results, the IMP contents were higher for samples at 2℃ or 10℃ after aging for 4 d than at 25℃, regardless of irradiation ($p<0.05$). On the other hands, the hypoxanthine contents were lower for samples at 2℃ or 10℃ after aging for 4 d than at 25℃ ($p<0.05$). Thus, optimal aging periods in pork for better taste and flavor can be 4 to 8 d at 2℃ to 10℃.

Table 6. Effect of different aging temperature on nucleotide-related compounds of pork shoulder treated by electron beam irradiation

Storage (days)	Temperature (℃)	IMP (mg/100 g)			Inosine (mg/100 g)			Hypoxanthine (mg/100 g)		
		Control	Irradiated (2 kGy)	SEM	Control	Irradiated (2 kGy)	SEM	Control	Irradiated (2 kGy)	SEM
0		121.84^{x}	87.82^{x}	2.42	47.27^{x}	36.00^{y}	0.24	20.87^{x}	12.69^{y}	0.46
2	2[1)]	65.27^{a}	68.56^{b}	4.12	40.19^{a}	40.25^{b}	0.58	26.1^{c}	20.76^{b}	1.82
	10	61.29^{by}	88.9^{ax}	0.69	40.49^{ay}	48.78^{ax}	0.47	29.67^{bx}	15.65^{cy}	0.24
	25	66.14^{ax}	42.73^{cy}	0.53	25.08^{by}	36.36^{ac}	0.41	34.20^{a}	33.16^{a}	0.32
	SEM	1.13	3.25		0.54	0.45		0.35	1.48	
4	2[1)]	78.99^{a}	76.38^{a}	0.70	55.17^{ax}	49.52^{ay}	0.48	16.46^{by}	19.27^{cx}	0.23
	10	52.92^{bx}	42.42^{by}	1.19	30.51^{by}	35.31^{bx}	0.92	34.14^{ay}	38.22^{bx}	0.97
	25	13.79^{cx}	7.67^{cy}	0.68	53.79^{ax}	29.69^{cy}	1.05	34.89^{ay}	48.26^{ax}	0.60
	SEM	0.94	0.84		0.83	0.87		0.70	0.64	
8	2[1)]	66.17^{ax}	64.61^{ay}	0.35	57.17^{ax}	47.29^{by}	0.22	18.32^{cy}	28.67^{bx}	0.24
	10	49.85^{by}	57.93^{bx}	0.36	46.65^{by}	57.8^{ax}	0.44	33.13^{bx}	27.92^{by}	0.35
	25	4.33^{c}	4.78^{c}	0.13	1.62^{cy}	11.43^{cx}	0.22	70.16^{a}	69.45^{a}	0.90
	SEM	0.18	0.38		0.29	0.33		0.70	0.42	

[1)] n=24, [2)] n=9.
[a-c] Values with different letters within the same column differ significantly ($p<0.05$).
[x, y] Values with different letters within the same row differ significantly ($p<0.05$).
IMP, inosine monophosphate.

Conclusion

An optimizing aging conditions of pork shoulders could be recommended at 2°C up to 8 d. The results of the present study concluded low-dose irradiating of EB (less than 2 kGy) followed by aging could inhibit microbial growth, promote generation of flavor compounds and tenderizing texture, and provide minimal detrimental effects of color and lipid oxidation.

Conflicts of Interest

The authors declare no potential conflict of interest.

Author Contributions

Conceptualization: Nam KC. Data curation: Park JY, Lee SY. Formal analysis: Park JY. Methodology: Lee SY. Validation: Jo C. Writing - original draft: Yim DG, Mahabbat A. Writing - review & editing: Yim DG, Jo C, Mahabbat A, Park JY, Lee SY, Nam KC.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

References

Ahn DU, Nam KC. 2004. Effects of ascorbic acid and antioxidants on color, lipid oxidation and volatiles of irradiated ground beef. Radiat Phys Chem 71:151-156.

Ahn DU, Olson DG, Jo C, Chen X, Wu C, Lee JI. 1998. Effect of muscle type, packaging, and irradiation on lipid oxidation, volatile production, and color in raw pork patties. Meat Sci 49:27-39.

Ba HV, Park K, Dashmaa D, Hwang I. 2014. Effect of muscle type and vacuum chiller ageing period on the chemical compositions, meat quality, sensory attributes and volatile compounds of korean native cattle beef. Anim Sci J 85:164-173.

Black JL, Jaczynski J. 2006. Temperature effect on inactivation kinetics of *Escherichia coli* O157:H7 by electron beam in ground beef, chicken breast meat, and trout fillets. J Food Sci 71:M221-M227.

Borch E, Kant-Muermans ML, Blixt Y. 1996. Bacterial spoilage of meat and cured meat products. Int J Food Microbiol 33:103-120.

Davis KJ, Sebranek JG, Huff-Lonergan E, Ahn DU, Lonergan SM. 2004. The effects of irradiation on quality of injected fresh pork loins. Meat Sci 67:395-401.

Degeer SL, Hunt MC, Bratcher CL, Crozier-Dodson BA, Johnson DE, Stika JF. 2009. Effects of dry aging of bone-in and boneless strip loins using two aging processes for two aging times. Meat Sci 83:768-774.

Du M, Hur SJ, Nam KC, Ismail H, Ahn DU. 2001. Volatiles, color, and lipid oxidation of broiler breast fillets irradiated before and after cooking. Poult Sci 80:1748-1753.

Flores M, Armero E, Aristoy MC, Toldra F. 1999. Sensory characteristics of cooked pork loin as affected by nucleotide

content and post-mortem meat quality. Meat Sci 51:53-59.

Frenzel LL, Harp RM, Lambert BD, Sawyer JT, Frenzel MA. 2014. Effects of wet aging and temperature on Warner-Bratzler shear force, sensory characteristics, and microbial shelf-life of pork loin chops. Texas J Agric Nat Resour 27:24-35.

Fu AH, Sebranek JG, Murano EA. 1995. Survival of *Listeria monocytogenes*, *Yersinia enterocolitica* and *Escherichia coli* O157:H7 and quality changes after irradiation of beef steaks and ground beef. J Food Sci 60:972-977.

Giroux M, Ouattara B, Yefsah R, Smoragiewicz W, Saucier L, Lacroix M. 2001. Combined effect of ascorbic acid and gamma irradiation on microbial and sensorial characteristics of beef patties during refrigerated storage. J Agric Food Chem 49:919-925.

Huff-Lonergan E, Lonergan SM. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci 71:194-204.

Jin SK, Kim CW, Chung KH, Jo KK, Jeong JY, Hur IC, Jung EY, Joo ST, Yang HS. 2012. Physicochemical and sensory properties of irradiated dry-cured ham. Radiat Phys Chem 81:208-215.

Jo C, Ahn DU. 2000a. Production of volatiles compounds from irradiated oil emulsion containing amino acids and proteins. J Food Sci 65:612-616.

Jo C, Ahn DU. 2000b. Volatiles and oxidative changes in irradiated pork sausage with different fatty acid composition and tocopherol content. J Food Sci 65:270-275.

Kim IS, Jo C, Lee KH, Lee EJ, Ahn DU, Kang SN. 2012. Effects of low-level gamma irradiation on the characteristics of fermented pork sausage during storage. Radiat Phys Chem 81:466-472.

Kim SY, Yong HI, Nam KC, Jung S, Yim DG, Jo C. 2018. Application of high temperature (14℃) aging of beef *M. Semimembranosus* with low-dose electron beam and x-ray irradiation. Meat Sci 136:85-92.

Korea Meat Trade Association [KMTA]. The survey of consum and distribution of meat-pork. Available from: http://www.kmta.or.kr/board/data/report01_3573_201702_p.pdf. Accessed at Jan 30, 2019.

Lee KH, Lee LS. 2001. Changes of nucleotides and their related compounds in cultured and wild red sea bream and flounder muscle. Korean J Food Soc Cook Sci 17:517-522.

Lee M, Sebranek J, Parrish FC. 1996. Accelerated postmortem aging of beef utilizing electronbeam irradiation and modified atmosphere packaging. J Food Sci 61:133-136.

Li C, He L, Jin G, Ma S, Wu W, Gai L. 2017. Effect of different irradiation dose treatment on the lipid oxidation, instrumental color and volatiles of fresh pork and their changes during storage. Meat Sci 128:68-76.

Mattison ML, Kraft AA, Olson DG, Walker HW, Rust RE, James DB. 1986. Effect of low dose irradiation of pork loins on the microflora, sensory characteristics and fat stability. J Food Sci 51:284-287.

Nam KC, Ahn DU. 2003. Effects of ascorbic acid and antioxidants on the color of irradiated ground beef. J Food Sci 68:1686-1690.

SAS. 2003. SAS/STAT Software for PC. Release 8.01, Sas Institute, Inc., Cary, NC, USA.

Shin MH, Lee JW, Yoon YM, Kim JH, Moon BG, Kim JH, Song BS. 2014. Comparison of quality of bologna sausage manufactured by electron beam or x-ray irradiated ground pork. Korean J Food Sci Anim Resour 34:464-471.

Sohn SH, Jang A, Kim JK, Song HP, Kim JH, Lee M, Jo C. 2009. Reduction of irradiation off-odor and lipid oxidation in ground beef by α-tocopherol addition and the use of a charcoal pack. Radiat Phys Chem 78:141-146.

Straadt IK, Rasmussen M, Andersen HJ, Bertram HC. 2007. Aging-induced changes in microstructure and water distribution in fresh and cooked pork in relation to water-holding capacity and cooking loss: A combined confocal laser scanning

microscopy (CLSM) and low-field nuclear magnetic resonance relaxation study. Meat Sci 75:687-695.

Tikk M, Tikk K, Torngren MA, Meinert L, Aaslyng MD, Karlsson AH, Andersen HJ. 2006. Development of inosine monophosphate and its degradation products during aging of pork of different qualities in relation to basic taste and retronasal flavor perception of the meat. J Agric Food Chem 54:7769-7777.

World Health Organization [WHO]. High dose irradiation: Wholesomeness of food irradiated with doses above 10 kGy. Available from: http://www.who.int/iris/handle/10665/42203. Accessed at Jan 30, 2019.

Yim DG, Jo C, Kim HC, Seo KS, Nam KC. 2016. Application of electron-beam irradiation combined with aging for improvement of microbiological and physicochemical quality of beef loin. Korean J Food Sci Anim Resour 36:215-222.

Zhu MJ, Mendonca A, Ahn DU. 2004. Temperature abuse affects the quality of irradiated pork loins. Meat Sci 67:643-649.